MISSOURI
DEPARTMENT OF
NATURAL RESOURCES

Rationale for Missouri Numeric Nutrient Criteria for Lakes

September, 2015

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Introduction

In August 2011, the United States Environmental Protection Agency (EPA) disapproved the majority of Missouri's numeric nutrient criteria (NNC) for lakes at 10 CSR 20-7.031(3)(N), citing concerns in regard to scientific rigor, reproducibility, and connection to designated uses (DU) (US EPA, 2011). The Missouri Department of Natural Resources, with the input of stakeholders, is proposing revised NNC for lakes and providing improved scientific rationale for criteria development while strengthening the link between the criteria and the DU of lake waters. This document outlines the rationale and scientific basis for these revised NNC and provides information to the public and interested parties from which to provide comments.

All lakes in Missouri's Water Quality Standards regulation have DU for aquatic habitat protection (AQL), human health protection (HHP), whole body contact recreation (WBC), secondary contact recreation (SCR), and livestock and wildlife watering (LWW). A number of lakes also have an additional DU of drinking water supply (DWS) (Missouri Secretary of State, 2014). The scope of DU to be considered by the revised NNC was decided through a series of stakeholder discussions that were part of the department's Water Protection Forum. It was decided through this forum that the focus of revised NNC development would concentrate on the AQL and DWS designated uses, as sufficient data and information exist from which to establish criteria for these DU. Research and information continue to develop at the national level with respect to nutrient impacts and criteria for the protection of recreational uses. Missouri intends to pursue NNC for recreational DU (i.e., WBC and SCR) during a future rulemaking, likely within the 5 – 10 year timeframe. This will allow studies currently underway by EPA and others on the effects of cyanotoxins on recreational uses to mature, and for the state to conduct user perception surveys of algae by the recreating public.

Regional EPA Section 304(a) criteria for nutrients are currently available in the form of Regional Ambient Water Quality Benchmarks for the protection of aquatic life (RTAG, 2011), and as Ambient Water Quality Criteria Recommendations for Lakes in Nutrient Ecoregion VI, Ecoregion IX, and Ecoregion XI (US EPA, 2000a,b,and c). These benchmarks and recommendations reflect a regional, reference condition approach to NNC development that is not representative of Missouri lakes due to differences in hydrology, landscape and other factors. Missouri lakes, with the exception of oxbow lakes in the Missouri and Mississippi River floodplains, are not natural hydrologic features, but rather are reservoirs that have been created through local, state or federal programs and efforts. These man-made impoundments render reference approaches to nutrient criteria development moot, as the water-bodies are themselves a significant human influence on the landscape. Also, the relatively recent construction of these reservoirs precludes the use of approaches to NNC development that focus on historic conditions (Kennedy, 2001).

EPA regional nutrient benchmarks and recommendations were developed to represent nutrient levels that protect against adverse over-enrichment of the water body. In its Ambient Water Quality Criteria Recommendations (e.g., USEPA 2000 a,b, and c), the agency recommended that states "critically evaluate this information in light of the specific designated uses that need to be protected." EPA rightly recognizes that optimal lake nutrient, or trophic, conditions for a specific DU do not necessarily coincide with optimal conditions for other uses. In particular, AQL favors a relatively high availability of nutrients to supply the food chain (Michaletz, Obrecht, & Jones, 2012; Downing & Plante, 1993; Ney, 1996). In contrast, DWS and WBC are optimal at lower nutrient content, which enhances water transparency and reduces the production of taste and odor compounds, disinfection byproduct precursors, and algal toxins (Falconer, et al., 1999; Knowlton & Jones, 2003). With these NNC revisions, Missouri critically evaluated the DU for which NNC were to be developed and regional differences in nutrient requirements for these DU. The proposed NNC and implementation framework are anticipated to ensure appropriate protection of all DU within a given ecoregion.

Trophic state refers to the biological production, both plant and animal life, that occurs in a lake or reservoir. All trophic classification is based on a division of the trophic continuum, of which there are no clear delineation of divisions (Carlson, 1977). Lakes with low nutrient concentrations and low levels of algal production are referred to as oligotrophic. Water-bodies with high nutrient levels and productivity are termed eutrophic. Mesotrophic lakes fall in between this continuum. Hypereutrophic lakes fall on the extreme high end of this continuum, and are characterized by excessive nutrients and are extremely productive in terms of algal growth. In these systems algal blooms may be frequent and severe. These blooms can lead to oxygen deficits when the bloom dies off and bacterial decomposition of the organic matter is maximized. Low oxygen concentrations can in turn negatively affect the aquatic life within the lake, causing reduced reproduction or lethality (i.e., fish kills) depending on the duration and intensity of dissolved oxygen decrease.

There is a relationship between geographical location and the occurrence of trophic conditions in Missouri lakes (Jones & Knowlton, 1993, Jones, Knowlton et al, 2008, Jones et al, 2009). Lakes in the northern and western parts of the state (Central Dissected Plains and Osage Plain ecoregions) tend to be more eutrophic and hypereutrophic, while lakes in the Ozark Highlands ecoregion are generally mesotrophic and oligotrophic. Lakes in the Ozark Border ecoregion have a range of trophic states that are generally lower than the Plains ecoregions, but higher than the Ozark Highlands (Jones, Obrecht et al., 2008). These regional differences in water quality reflect geological, topographical and cultural land use differences across the state.

The current NNC revision takes into account aquatic life and drinking water protection DUs assigned to lakes within each of the ecological regions. Lakes that are used for DWS have criteria that are specific to that particular use within the Plains ecoregion. Lakes in the Ozark ecoregion have more conservative NNC for AQL than for DWS. Since all lakes are assigned AQL, and the most protective use governs the applicable criteria, there is no distinction made for DWS between the regions. Distribution of lakes in Missouri ecoregions is described in Table 1.

Table 1. Distribution of Lakes in Missouri Ecoregions.

Lake Class*	Description	Plains	Ozark Border	Ozark Highland
L1	Lakes used primarily for public drinking water supply	103	3	5
L2 (DWS)	Major Reservoirs that include DWS	4	0	3
L2 (Other)	Other major reservoirs	1	0	7
L3	Other lakes	525	151	245
Totals		633	154	250
Grand Total		1,037		

*Lake class per 10 CSR 20-7.031(1)(F)1. – 3. Lake count from Missouri Use Designation Dataset, Version 1.0, August 20, 2013.

Setting Criteria

Both causal (e.g., phosphorus and nitrogen) and response (e.g., turbidity and chlorophyll-a (chl-*a*)) variables were evaluated to develop Missouri's recommended lake nutrient criteria. Causal variables are linked to biological responses (i.e., increase in primary productivity), and when in excess, can cause water quality impairments associated with accelerated algal growth. Accelerated and prolonged algal growth can have several adverse effects on designated uses. Reductions in dissolved oxygen caused by algal respiration and decay, unsightly algal blooms, reduced water transparency and, in some cases, the production of microcystins and other toxins by certain algae species (notably some of the cyanobacteria, also known as blue-green algae) can all occur and in varying degrees. While eutrophication (i.e., nutrient enrichment) of lakes is a natural process in the landscape, anthropogenic inputs of nutrients, as well as changes in hydrology and climate, can accelerate and exacerbate the natural processes. Minimizing and eliminating the frequency and occurrence of these adverse effects, and attainment of DU, is the driver for Missouri's NNC efforts.

Conceptually, the link between nutrient sources and designated uses involves multiple steps (Figure 1). Whereas most environmental stressors are generally thought of as being directly toxic (either acutely or chronically), the effects of nutrient over-enrichment are causal and consequential in nature (i.e.,., nutrients drive productivity, which can deplete oxygen when algae dies off, causing detrimental impacts on organisms). Additionally, biological responses to nutrients can vary based on site-specific physical, chemical and hydrologic factors. For example, flushing rates, which vary between reservoirs, may limit the impact of phosphorus loading on water column concentrations, which ultimately stimulate phytoplankton production (EPA, 2000). Turbidity and grazing pressure by zooplankton also serve as confounding factors.

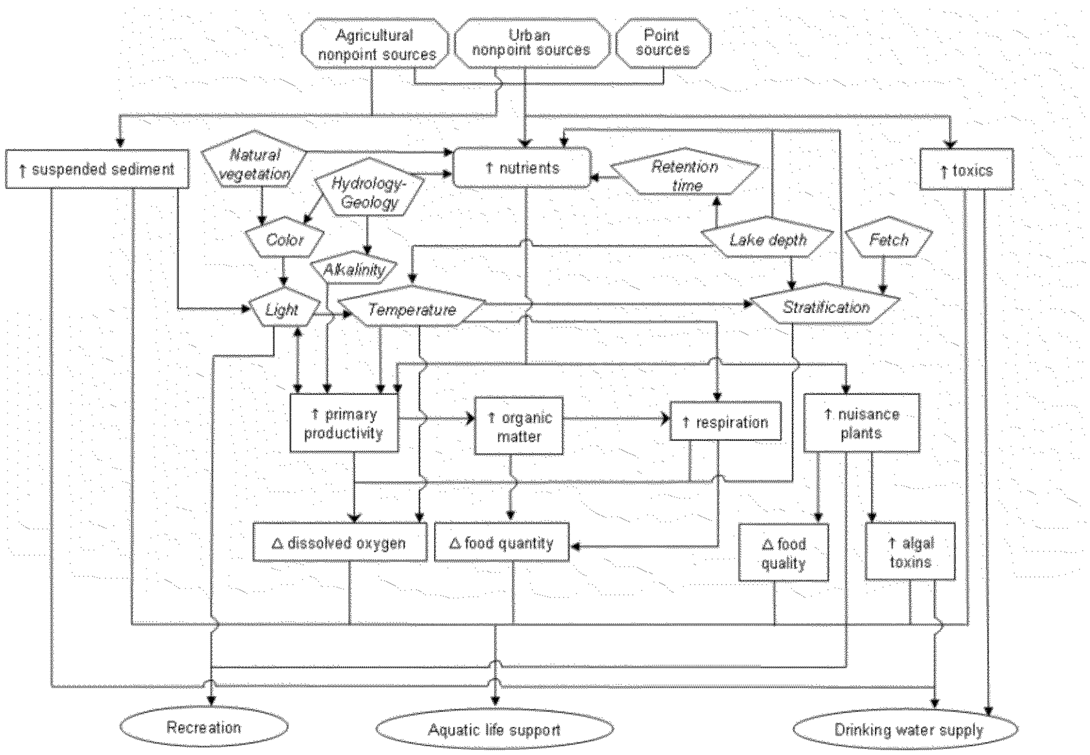

Figure 1. Conceptual Nutrient Model Diagram for Lakes (USEPA, 2010)

Missouri is establishing revised NNC for lakes using methods and considerations established in guidance by the EPA (US EPA, 2000d). In evaluating existing data and the types of lake features represented in those data, it becomes clear that few natural lakes exist in Missouri. Most lake features are man-made impoundments of surface waters for which the primary purpose is other than recreation (e.g., swimming, boating or fishing). (US EPA, 2000d) Many were constructed for flood control, drinking water supply or hydropower generation. Reservoirs differ from natural lakes in that they exhibit a trophic gradient as they lose nutrients through settling in the downstream direction. A reservoir may naturally range from eutrophic in its upper reaches to oligotrophic near the dam. Reservoirs also tend to have lower chl-*a* levels at the same phosphorus concentrations than natural lakes due to higher inorganic turbidity and flushing rates (Soballe & Kimmel, 1987). Lake features covered by NNC remain those with a surface area greater than 10 acres, the minimum size feature likely to have mean residence times and flushing rates where nutrient enrichment can be an issue.

Empirical links between chlorophyll and phosphorus have been extensively studied and are well established, particularly in Missouri. In Missouri reservoirs, total phosphorous (TP) accounts for 79% of the cross-system variation in chlorophyll and there is a 5-fold range of Chl-a:TP ratios among long-term means. Residual variation is likely due to lake-specific conditions including sediment influx (Jones & Knowlton, 2005). A more recent analysis of water quality data within each of the ecological regions, conducted by the department, also indicates significant correlations between TP and chl-*a* (Figure 2). Correlations between total nitrogen (TN) and chl-*a* are generally not as strong, but are nevertheless significant.

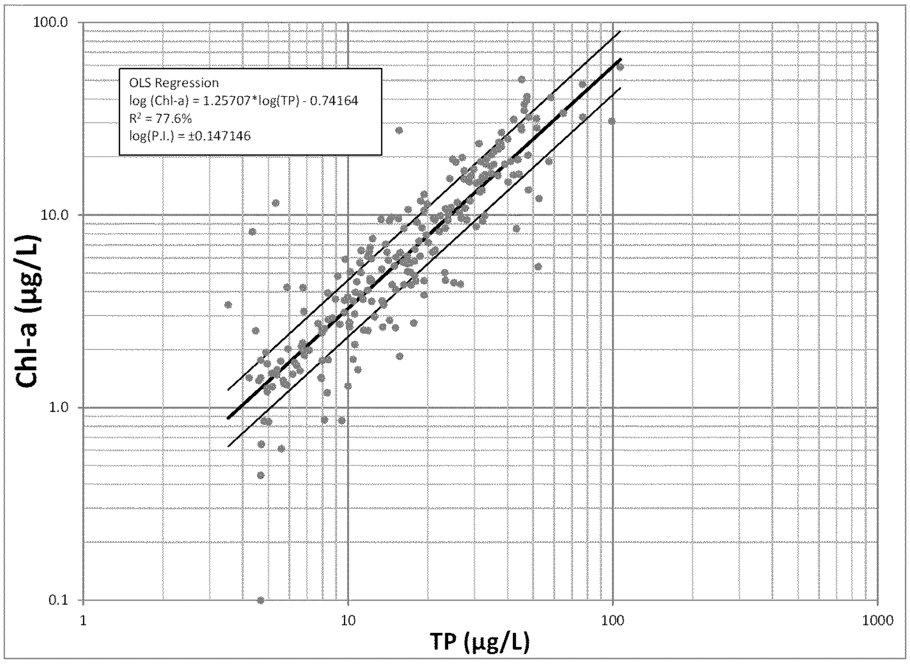

Figure 2. Chlorophyll-a - Total Phosphorus Plot of Annual Geomean Reservoir Data in the Ozark Highlands Region

While the biotic response to nutrient enrichment at specific concentration levels is relatively well established in reservoirs, the department is not recommending use of traditional fixed-threshold nutrient (phosphorus and nitrogen) criteria. Because the effects of nutrient over-enrichment are causal (i.e., nutrients, themselves, are generally not toxic), linking causal variables (i.e., phosphorus and nitrogen) to adverse impacts involves greater uncertainty and site-specific considerations than linking response variables (chl-*a*). Less uncertainty and ecoregional applicability can be gained by utilizing response variable correlations to protect and prevent against adverse impacts. For this reason, the department is recommending that a biological variable, chl-*a,* serve as the basis for establishing nutrient criteria. Chl-*a* is the most common method of measurement of the abundance of algae in a water body and can be related to a number of factors directly impacting DU (e.g., algal blooms, low dissolved oxygen and algal toxins). Additionally, adopting chl-*a* resolves the issue that reservoirs exhibit variable sensitivity to nutrient enrichment based on their flushing rate, critical depth, sediment influx, and other factors. Most importantly, chl-a provides nutrient criteria based on a biological variable directly indicative of the health and status of a lake system and its DU.

Although a biological endpoint is being recommended as Missouri's NNC, the department recognizes the importance of including causal nutrient variables, like TP and TN, and other candidate variables (e.g., Sechhi depth and dissolved oxygen) in a holistic approach to lake nutrient management. To this end, the department is proposing the use of screening values to identify reservoirs in need of further evaluation where chl-a values are acceptable. Screening values will allow for assessment and determination of conditions that set the potential for adverse impacts to DU and reduce uncertainty in impairment decisions. Under this approach an upper chl-*a* concentration would be established as the criterion above which designated uses are impaired (Figure 3). A lower set of screening values (chl-*a*, TN and TP) would also be set, below which designated uses are considered to be attained. Lakes with nutrient or chl-a concentrations above the screening values but with chl-a concentrations less than criteria would be in the "gray zone" and would require a weight of evidence evaluation.

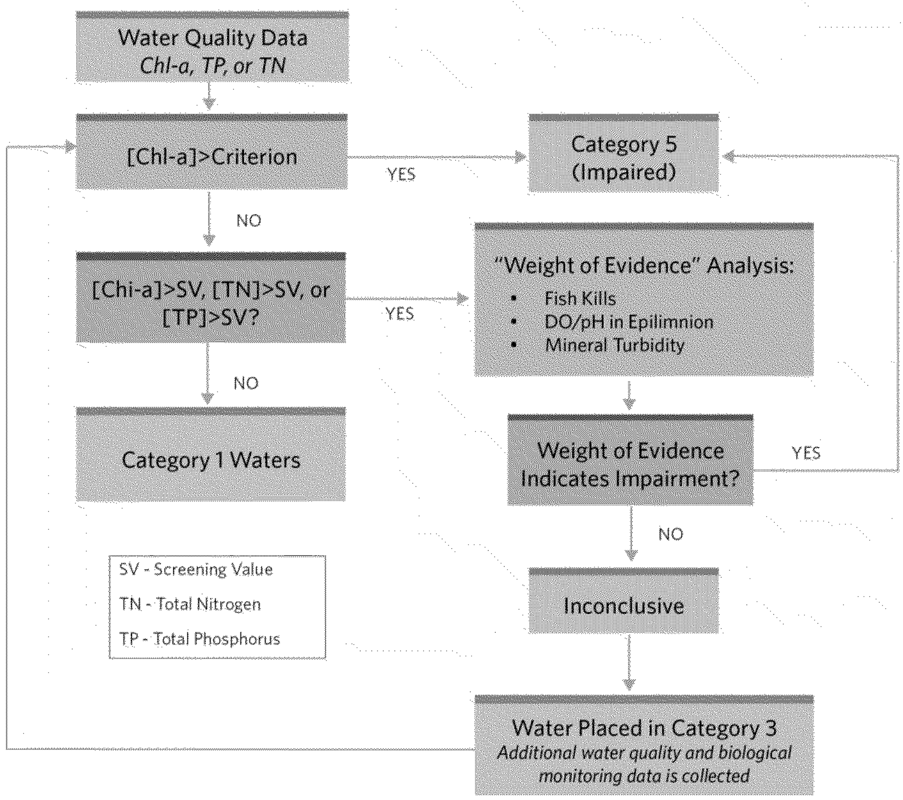

Figure 3. Screening Approach

This weight of evidence evaluation for aquatic life protection includes assessing the occurrence of harmful algal blooms, fish kills, wide diurnal fluctuations of dissolved oxygen, and high turbidity levels that may impact beneficial uses. In lakes that are sources for drinking water, the weight of evidence evaluation includes the occurrence of disinfection byproducts in treated water, taste and odor issues, the presence of algal toxins, and significant impacts on water treatment plant operations. Lakes will be listed as impaired if one or more of these factors is determined to be significant to the point of impairing either the aquatic life protection or drinking water supply DU. Lakes found not to be impaired will be placed in Category 3 of Missouri's Integrated Report (i.e., Missouri's 305(b) report) where water quality data are not adequate to properly assess the designated use. Lakes in Category 3 would then be prioritized for additional chemical and biological monitoring by the department.

The concept of a "gray zone" was widely discussed during theEPA's expert workshop on nutrient enrichment in streams convened in April 2013 (US EPA, 2014). Some experts believed a "grey zone" is necessary, noting the uncertainty associated with establishing a single threshold value (USEPA, 2013). Such a concept has also been proposed by other states, including Virginia and Arizona. The department concurs with the findings from the expert workshop and asserts that this approach provides a sound scientific rationale for protecting designated uses.

Applicable water quality criteria must be expressed in the terms of magnitude, duration and frequency. The department recommends that chl-a criteria and nutrient screening values be expressed as geometric mean values. Geometric means will be used because nutrient concentrations have a log-normal distribution. The chl-*a* criteria will be based on a long-term duration as defined by at least 3 years of data. A long-term duration of three or more years is necessary to account for natural variations in nutrient levels due to climatic variability. (Knowlton & Jones, 2006). Additionally, two sets of screening values for chl-*a*, total phosphorus (TP) and total nitrogen (TN),) based on a long-term (i.e., minimum of 3 years) and short-term (i.e., 1 year) periods, provide additional opportunities to screen reservoirs for potential impairments. Potential lake impairment is more clearly associated with chl-a concentration than TP or TN concentration, and the short-term chl-a screening value represents a maximum acceptable concentration. Therefore, the magnitude of the short-term chl-*a* screening value is proposed to be equal to the magnitude of the chl-*a* criterion. The magnitude of the long-term chl-*a* screening value will be set to a lower value based on rationale provided in the following section. Short-term and long-term TP and TN screening values are based on regional regressions and the magnitude of the respective chl-*a* screening values as described in the "Calculation of Screening Values" section.

Designated Uses and Criteria

Rationale for the magnitude of chl-*a* criteria and nutrient screening values are provided below for public drinking water supply and aquatic habitat protection DU.

Public Drinking Water Supply

Eutrophication in lakes that serve as public drinking water supply can give rise to several issues, including taste and odor problems, higher treatment costs, and potential health hazards. The last impact may come in the form of cyanotoxins or disinfection byproducts, notably trihalomethanes(THM).

One potential approach for setting criteria protective of drinking water supplies is to target nutrient concentrations that limit algal blooms, which are closely linked to algal toxins and high levels of organic carbon that may be disinfection byproduct precursors. Algal bloom frequency is thought to be a better indicator of potential use impairment than trophic status alone (Heiskary and Walker, 1988). Some studies have suggested that algal bloom frequency increases exponentially when mean chl-*a* levels exceed 10 μg/L (Walker, 1985; Falconer, 1999; Downing et al., 2001). However, these findings are based on interpretations of relatively poorly defined relationships. Additionally, these studies may be more applicable to lakes than reservoirs. Downing et al. (2001) excluded reservoirs from their study of algal blooms; potentially due to the fact that reservoirs typically respond differently to nutrient enrichment than natural lakes.

Another potential approach to setting criteria is to target chl-*a* levels that minimize compounds responsible for taste and odor issues. Two such compounds, geosmin (trans-1, 10 dimethyl-trans-9-decalol) and MIB (2-methyl isoborneol), have been strongly associated with blue-green algae blooms. Smith et al (2002) found a strong predictive relationship between geosmin and chl-*a* concentrations. From this relationship, Smith et al provisionally suggested that taste and odor problems would cease when chl-*a* concentrations are maintained at a level below 10 μg/L (Figure 4). However, the Smith et al recommendation was based on an assumed odor threshold of 5 ng/L for geosmin, which varies between studies. For example, the American Water Works Association (2008) uses a geosmin threshold of 10 ng/L. Also, the Smith et al work was limited to a single shallow reservoir in Kansas; given the natural variations in how the physical, chemical and biological facets of reservoirs interact, the findings of this study may not be applicable to all water bodies.

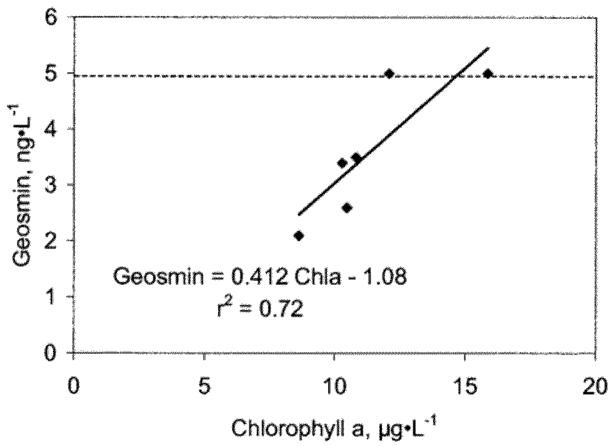

Figure 4. Relationship between station mean concentrations of geosmin and chlorophyll-a in Cheney Reservoir, USA. (From Smith et al (2002). The horizontal dotted line indicates an approximate threshold concentration of geosmin for human detection.)

For purposes of establishing a drinking water criterion, Missouri is targeting a chl-*a* criterion to control microcystin[1]. Microcystin is the most common toxin produced by cyanobacteria within algal blooms. A hepatotoxin, microcystin has been documented to pose chronic and acute health risks to livestock, pets, and humans. The World Health Organization (WHO) has adopted a provisional guideline value for lifetime exposure of 1,000 ng/L (1.0 µg/L) for microcystin[2] (Falconer, et al., 1999). In a study of 241 lakes in Missouri, Iowa, northeastern Kansas, and southern Minnesota, Graham et al (2004) found that microcystin is common in lakes, but generally at low levels. Reported median microcystin-LR concentrations in Missouri regions were at or below 2 ng/L (Table 2). Graham and Jones (2009), following up on the 2004 study, found that relatively few lakes in Missouri had microcystin concentrations greater than the WHO finished drinking water guideline of 1 µg/L. The mean chl-*a* concentrations associated with microcystin-LR levels ranging from the detection limit (0.1 µg/L) to the WHO guideline (1 µg/L) was reported as 26 µg/L (Table 3).

Based on these findings, the magnitude of the chl-*a* criteria and screening values for drinking water

[1] Microcystins are a family of compounds. The most extensively studied member is microcystin-LR (5R,8S,11R,12S,15S,18S,19S,22R)-15-[3-(diaminomethylideneamino)propyl]-18-[(1E,3E,5S,6S)-6-methoxy-3,5-dimethyl-7-phenylhepta-1,3-dienyl]-1,5,12,19-tetramethyl-2-methylidene-8-(2-methylpropyl)-3,6,9,13,16,20,25-heptaoxo-1,4,7,10,14,17,21-heptazacyclopentacosane-11,22-dicarboxylicacid.

[2] The guideline value is based on the following assumptions: Average adult body weight (bw) is 60 kg, a provisional total daily intake (TDI) set at 0.04 µg kg^{-1}, of which a proportion (P) of 0.8 is allocated to drinking water, and water consumption of 2 L d^{-1}. It is calculated as follows: ,which comes to 0.96 µg L^{-1}, and is rounded up to 1.0 µg L^{-1}.

supply DU are summarized in Table 4. Long-term and short-term screening values for TP and TN are based on regional regressions and the chl-*a* screening values as summarized in the "Calculation of Screening Values" section.

Table 2. Regional Medians and Ranges of Microcystin Values (Adapted from Graham and Jones (2004)).

Region	Microcystin-LR (ng/L)		
	n	Median	Range
Ozark Highlands	92	0[a]	0-43
Osage Plains	111	0[a]	0-189
Dissected Till Plains	439	2[b]	0-2,933

n indicates the number of lake visits in each region. Letters indicate significant differences in median concentrations (Kruskal-Wallis, $p<0.01$).

Table 3. Comparison of Chlorophyll Levels Among Three Microcystin Concentration Categories (Adapted from Graham and Jones (2009)).

Microcystin-LR (ng/L)	Chlorophyll (µg/L)		
	n	Mean	Range
nd	1,082	11[a]	1-342
0.1 - 1	271	26[b]	1-306
>1	49	46[c]	3-140

n indicates the number of lake visits in each region. Letters indicate significant differences in mean values.

Table 4. Chlorophyll-a Criterion and Screening Values for Drinking Water Supplies

	Magnitude (µg/L)	Rationale
Criterion	26	Protects for WHO microcystin-LR guideline of 1.0 µg/L based on Graham and Jones (2009)
Long-Term Screening Value	10	Conservative literature based value protective of algal blooms and taste and odor issues
Short-Term Screening Value	26	Same value as criterion with more conservative averaging period

Protection of Aquatic Habitat

Lakes in Missouri provide habitat for a variety of fish species, most of which are naturally reproducing populations within the lakes. Table 5 lists and describes fish species which are common in smaller lakes (<1,000 acres) (MDC, 2012).

Table 5. Common fish species found in small lakes of Missouri.

Common Name	Scientific Name	Habitat and other comments[3]
Common Carp	*Cyprinus carpio*	Invasive species. Introduced from Asia in 1879. Abundant in man-made impoundments that are highly productive as a result of runoff from heavily fertilized farmlands or other pollutants. Often compete for food with more desirable species. Feeding habits result in deterioration of habitat through increased turbidity and destruction of aquatic vegetation. Feeding activity may result in increased nutrient loading.
Gizzard Shad	*Dorosoma cepedianum*	Appears in clear and turbid waters, prefers those where fertility and productivity are high.
Channel Catfish	*Ictalurus punctatus*	Common in large rivers. Hatchlings have low survival rate in clear waters, higher in turbid waters. Therefore they need periodic restocking in some lakes.
Green Sunfish	*Lepomis cyanellus*	Tolerates wide range of conditions, including extremes of turbidity, dissolved oxygen and temperature. Among the first to repopulate prairie streams following droughts.
Bluegill	*Lepomis macrochirus*	Intolerant of continuous high turbidity. Thrives in clear water where aquatic plants or other cover is present.
Redear Sunfish	*Lepomis microlophus*	Does best in warm, clear waters with no noticeable current and an abundance of aquatic plants.
Largemouth Bass	*Micropterus salmoides*	Thrives in warm, moderately clear waters with no current.
White Crappie	*Promoxis annularis*	Commonly in areas with standing timber or other cover. Spring spawning in shallow water near upper ends of coves.
Black Crappie	*Promoxis nigromaculatus*	Sporadic distribution, most prevalent in large Ozark reservoirs. Less common and less tolerant of turbidity and siltation than White Crappie.

While the ideal physical habitats for these species vary considerably, they generally have in common a requirement for some degree of aquatic productivity to thrive. Most of these species do well in eutrophic conditions and there is substantial literature that describes a need for higher nutrient concentrations to support healthy fisheries (Knowlton & Jones, 2003). Jones and Hoyer (1982) found a strong positive relationship between chl-*a* concentrations, up to 70 µg/L, and sport fish yields in

[3] Summarized from descriptions by Pflieger (1975).

Missouri and Iowa lakes. Michaletz et al (2012) reported that growth and size structure of sport fish populations increased with water fertility, due to abundance of prey in more fertile waters. There is, however, an upper limit of aquatic productivity beyond which fish population declines. Michaletz et al also reported, among other findings, that for largemouth bass and black crappie, fish size distributions had a threshold of 40 to 60 µg/L for chl-*a*, and above this range fish sizes declined. Additionally, largemouth bass and redear sunfish Catch Per Unit Effort (CPUE) were particularly low when TP exceeded 100 µg/L,the level of TP that approximates the threshold of hypereutrophy (Carlson & Simpson, 1996; Jones, Obrecht, et al., 2008).In addition to the above findings, Egertson and Downing (2004) reported that in Iowa lakes, high concentrations of chl-*a* were associated with a decline in fish species diversity. Specifically, on a chl-*a* gradient of 10 to 100 µg/L, CPUE for common carp and other benthivore species increased. This appeared to be at the expense of CPUE for more desirable species, notably bluegills and black crappie. While the declines of the latter were not statistically significant, the study suggests that highly eutrophic conditions disfavor piscivores, which are mainly visual feeders.

Following a review of these and other findings, staff from the Missouri Department of Conservation (MDC) and the University of Missouri (MU) provided chl-*a* concentrations that would support warm water fisheries in smaller lakes (Table 6). The concentrations provided by MDC and MU for the Plains are conservative to support sports fisheries, rather than maximizing sport fish harvest. Sport fish biomass does not peak at less than 100 µg/L TP (about 39 µg/L chl-*a*) (Ney 1996), and sport fish maintenance, rather than maximization, should allow multiple DUs to be attained. For the Ozark Highlands, MDC and MU provided a lower chl-*a* concentration of 15 ug/L for maintenance of sports fisheries. These waters are situated in less fertile landscapes, and large reservoirs contain species characteristic of clear Ozark streams that are likely more sensitive to high nutrient concentrations. The Ozark Border section represents a transition zone between the Plains and Ozark Highlands; therefore, MDC and MU provided a chl-*a* criterion intermediate to the other two sections.

Table 6: MDC and MU recommendations for chl-*a* criteria for Missouri lakes.

Lake Ecoregion	Chl-*a* (µg/L)
Plains	30
Ozark Border	22
Ozark Highlands	15

In developing the aquatic habitat protection criteria, consideration was also given to the prevailing lake trophic conditions that were characteristic of each ecoregion. Although trophic status itself is not the same as a water quality index, the use of prevailing trophic conditions offers an approach for establishing regional goals and expectations (Carlson, 1977). In the Plains, most lakes are eutrophic whereas in the Ozark Highlands, most lakes are mesotrophic, and several are oligotrophic. Lakes in the Ozark Border ecoregion are a transition between mesotrophic and eutrophic. These regional differences in water quality reflect variations in geology, land use and topography across the state. The concept of criteria varying by ecoregion was also set forth in EPA's *Nutrient Criteria Technical Guidance Manual* (2000), which lists the Missouri Plains region as part of Ecoregion XI – The Central and Eastern Forested Uplands, while the Ozark Highlands are considered to be in Ecoregion IX – Southeastern Temperate Forested Plains and Hills. Trophic state thresholds proposed by Jones et al (2008) for Missouri reservoirs are presented in Table 7.

Table 7. Trophic state thresholds for Missouri reservoirs (Jones et al. 2008)

Trophic State	Upper Limit of Chl-*a* for Trophic State (µg/L))
Oligotrophic	3
Mesotrophic	9
Eutrophic	40

Criteria for chl-*a* in the Plains is set at 40 µg/L to approximate the threshold between eutrophic and hyper-eutrophic conditions (Jones, et al., 2008). Suggested criteria for the Ozark Highland and Border ecoregions are based on information provided by the MDC and MU. Long-term screening values are more conservatively based on central (median) values corresponding to the prevailing trophic conditions in each ecoregion. The suggested long-term chl-a screening values are 20 µg/L for the Plains, 9 µg/L for the Ozark Border, and 7 µg/L for the Ozark Highlands. Chl-*a* criteria and screening values are summarized in Table 8. Long-term and short-term screening values for TP and TN are based onregional regressions and the chl-*a* screening values as summarized in the "Calculation of Screening Values" section.

Table 8. Chlorophyll-*a* Criteria and Screening Values for Aquatic Habitat Protection

Limit Type	Region	Chl-*a* (µg/L)	Rationale
Criterion	Plains	40	Protects sports fisheries and reflects prevailing trophic conditions within the region
	Ozark Border	22	
	Ozark Highland	15	
Short-Term	Plains	40	Same value as criterion with more conservative averaging period

Screening Value	Ozark Border	22	
	Ozark Highland	15	
Long-Term Screening Value	Plains	20	Central values corresponding to prevailing trophic conditions within the region
	Ozark Border	9	
	Ozark Highland	7	

Calculation of Screening Values

Data for nutrient screening value analyses were collected by the Lakes of Missouri Volunteer Program (LMVP) and the Statewide Lake Assessment Program (SLAP). The data used were from the years 2003 – 2013. A brief statistical description of these data is in Table 9.

Table 9: General statistics for lake data employed for criteria derivation.

Region	Number of Lakes	Yearly Geomeans (n)	Parameter Concentration Averages (Ranges)		
			TP (µg/L)	TN (µg/L)	Chl-a (µg/L)
Plains	140	611	61 (9 – 302)	909 (305 – 2660)	25 .1 (0.3 – 133.2)
Ozark Border	31	87	59 (5 – 291)	834 (243 – 2781)	21.7 (0.9 – 100.4)
Ozark Highlands	48	228	21 (4 – 107)	450 (75 – 1279)	10.0 (0.0 – 58.7)

To derive long-term and short-term screening values for TN and TP, regressions were conductedwith chl-*a* as the response variable. To account for seasonal variation of chl-*a* response, and to ensure sufficiency of data for each ecoregion, yearly geometric means of TN, TP, and chl-*a* concentrations for individual lakes were treated as the data points. This approach is consistent with criteria derivation methodology published by EPA (2010).

Each of the regression equations was recalculated using iterative weighted least squares one time (Helsel & Hirsch, 2002). TN and TP screening values were then derived by back calculating the regression equations using the chl-*a* values that were determined for each of the ecoregions. Results are in Tables 10a and 10b.

Table 10a: Regressions of $\log_{10}$ (Chl-*a*) response to $\log_{10}$ (TP) using annual geometric means.

Region	Slope	Intercept	R^2 (%)	Short Term (µg/L)		Long Term (µg/L)	
				Chl-*a*	TP	Chl-*a*	TP

Plains (AQL)	1.03824	-0.456854	80.5	40.0	96	20.0	49
Plains (DWS)				26.0	64	10.0	25
Ozark Border	1.06947	-0.56602	89.3	22.0	61	9.0	26
Ozark Highlands	1.28686	-0.77184	92.8	15.0	33	7.0	18

Table 10b: Regressions of log_{10} (Chl-*a*) response to log_{10} (TN) using annual geometric means.

Region	Slope	Intercept	R^2 (%)	Short Term (µg/L)		Long Term (µg/L)	
				Chl-*a*	TN	Chl-*a*	TN
Plains (AQL)	1.64908	-3.53766	80.9	40.0	1,308	20.0	857
Plains (DWS)				26.0	1,008	10.0	564
Ozark Border	1.76583	-3.9239	81.4	22.0	960	9.0	579
Ozark Highlands	1.53273	-3.1842	69.6	15.0	699	7.0	425

Discussion

The department's recommendations are based on the goal of establishing scientifically defensible lake nutrient criteria that are clearly linked to designated uses. The approach recommended herein provides an alternative to traditional fixed-threshold criteria, which too frequently lead to false declaration of DU impairment (and false declaration of DU attainment). This approach will allow the department to focus its efforts and resources on those reservoirs most likely in need of restoration.

Owing to the complexities and uncertainties of linking causal variables (phosphorus and nitrogen) to response variables and DU, the recommended criteria are based on biological attributes (i.e., chl-*a*). Chl-*a* is an ideal criterion because it is directly related to a number of factors that have a direct effect on the conditions of a lake to meet its designated uses (e.g., algal blooms, algal toxins, low dissolved oxygen, and taste and odor). Using chl-*a* criteria avoids falsely identifying lakes as impaired where nutrient levels may be high, but algal production is constrained by low autotrophic potential (e.g., fast flushing and low critical depth).

To limit the possibility of false negatives, the department is further recommending the use of screening values. Proposed screening values were conservatively established such that a high degree of confidence exists that reservoirs with nutrient concentrations below these levels are not impaired by nutrients. Where screening values are exceeded but the chl-*a* criterion is not, the department is recommending a weight of evidence evaluation. Such an evaluation would consider additional factors, such as the occurrence of harmful algal blooms and fish kills, to more definitively determine whether or not the DU is being attained.

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